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CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 21 July 1999 with an application for Letters Patent number 336855 made by UNITEC INSTITUTE OF TECHNOLOGY.

Y

Dated 2 August 2000.

Neville Harris

Neville Harris
Commissioner of Patents

COMMISSIONER OF PATENTS, TRADE MARKS & DESIGNS
NEW ZEALAND

336855

NEW ZEALAND

PATENTS ACT, 1953

PROVISIONAL SPECIFICATION

"Multi-Phase Flow Pumping Means"

We, **UNITEC INSTITUTE OF TECHNOLOGY**, a New Zealand institution under the Education Act 1989 of Carrington Road, Mt Albert, Auckland, New Zealand, do hereby declare this invention to be described in the following statement:

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INTRODUCTION

The present invention relates to improvements in or relating to multi-phase flow pumping means.

BACKGROUND ART

Two-phase fluid pumping covers a large spectrum of pump operation and applications. In certain situations the entrained gas will cause unwanted problems in the pumping process For the off-shore oil industry there is now considerable interest in pumping liquids with a high gas content, similar as there has been for some time in the pumping systems supplying aircraft gas turbines. This interest is also found within the geothermal industry. In many oil fields, the wells contain mixtures of gas and oil in varying proportions. The handling of such fluids can create problems. The problems are strictly multi-phase, which essentially means that as the gas or steam content increases the pressure head degrades when a normal centrifugal pump design is used. In two phase flow we are dealing with both a compressible and substantially incompressible fluid and the coexistence of liquid and vapour phases, it is very difficult and complex to describe hydro-dynamic behaviour.. The composition of the fluid flow and variety of flow configurations where each phase has a different velocity in such cases makes it the flow difficult to define. Particularly as the flow composition and configurations vary over time, and may reach gas volume percentages as high as 90 to 100 percent.

Flow separation of the different fluids prior to pumping or inside of the pump is a common way of dealing with delivery of multi-phase flow. This is for example illustrated in the specification of US patent 5580214.

The present conventional designs of centrifugal pumps are not adequate due to their inability to pump high gas volume fraction media. Better gas delivery is claimed if the blade passages are much larger, and work by *A Furukawa : "Fundamental studies on tandem blades impeller of gas liquid two phase centrifugal pump" Memoirs of the Faculty of Engineering Kyushu University, 48,4,231-40 or "On an improvement in air/water two phase flow performance of a centrifugal pump in the partial flow rate of water." 69th JSME Fall Annual Meeting, vol.B, paper number 1118, pp.165-7[1]* suggests using tandem or slotted blades to reduce the degradation in a limited range.

It is known that where free gas is present in a liquid being pumped the head, power and efficiency of rotodynamic pumps are known to decrease. (See figure 1).

A very peculiar property of two-phase flow media is the large influence of gas content on the speed of sound. The wave velocity in air/water mixture drops far below its value for either the liquid (1000 m/s at 20°C) or gas (340 m/s at standard pressure and temperature conditions) phase reaches values of about 25 m/s at 10 percent gas content. Normal values of peak relative velocities around the blade leading edge are in this range.

Therefore, pumps operate at transonic or supersonic local flow. It is not surprising that a blade design for incompressible single-phase flow is not very effective and produces choking for relatively high gas volume fraction. Theory shows that the dramatic variation of the speed of sound at low percentages is very much related to the large difference in density between the two phases. The sonic velocity in two-phase mixtures is also pressure dependent. Therefore, one would expect that head performance of pumps handling two-phase mixtures depend on the suction pressure.

BRIEF DESCRIPTION OF THE INVENTION

For rotodynamic pumps, the above mention problem may be solved with appropriate installation or modification of the impeller The objective of this invention is to provide the rotodynamic pumps with the aim of making a contribution in the area by

a) Outlining new theoretical insights and design approaches that might lead to a successful multi-phase flow pump for medium gas content,
b) discussing the design problems of pumps for high gas content,
c) exposition of the fundamentals of multi-phase pumping via rotodynamic means, including the fluid dynamical considerations,
d) describing multi-phase pumping of crude oil / steam and substances in order to illustrate how the design conclusions are reached,
e) suggesting several design alternatives for impeller including the variable speed, or
f) providing the public with a useful choice

It is suggested that the bleeding system which has been described in our international PCT application PCT/NZ99/00029, the contents of which is hereby to be read to be included in full in this specification, that such difficulties as hereinbefore detailed, may be alleviated.

Accordingly in a first aspect the present invention broadly consists in a pumping arrangement for pumping multi-phase flow with gas/steam content variable from zero percent to 100 percent in an unseparated mode said multi-phase pump arrangement comprising:

a centrifugal pump having an inlet and an outlet, said pump driveable by a power providing means (e.g. an electric motor),

a fluid communication providing means to provide a communication of fluid pressure and/or flow between the output side of said pump and said input side of said pump said fluid communication being such as to provide a fluid connection between said output side and said input side to deliver fluid of a higher pressure from said output side into said input side of said centrifugal pump,

wherein said centrifugal pump is provided with an impeller which has a blade or

vane configuration of increased passage way when compared to a conventional centrifugal pump which would operate in or near optimum conditions when pumping purely liquid, and

wherein said impeller is not of a substantially greater diameter than such conventional pumps.

Preferably said fluid connection between said output and said input side of said centrifugal pump is provided with at least one nozzle at the point of injection to inject fluid into said input side.

Preferably said nozzle is oriented in respect of the intake side so as to provide a pre- rotation of said intake fluid in respect of said centrifugal pump.

Preferably said pre-rotation is in a direction co-rotatory with said impeller rotation direction.

Alternatively said pre-rotation is in a direction anti-rotatory with said impeller rotation direction.

In a further aspect the present invention consists in a pumping arrangement for pumping multi-phase flow with gas/steam content variable from 0 percent to 100 percent in an unseparated condition. Said multi-phase pumping arrangement comprising:

a) a centrifugal pump provided with an impeller wherein the vane configuration provides an increase passage way for fluid, when compared to the passage way of a centrifugal pump commonly used for pumping purely liquid in substantially optimum or near optimum, and

b) an injection system as described in International Patent Application PCT/NZ99/00029.

In a further aspect the present invention consist in a pumping arrangement comprising a bleeding system as herein described with reference to the detailed description and the contents of our PCT specification PCT/NZ99/00029 in association with and impeller design of a kind where the impeller is in accordance with the geometry as shown in the accompanying figures.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph illustrating, as is commonly known, that when the gas contents of a fluid being pumped increase, there is a reduction in the head (H) and flow rate (Q) characteristics,

Figure 2 is a schematic layout of an arrangement for pumping of multi-phase fluids utilising an injection,

Figure 3 illustrates a layout of a multi-phase testing arrangement which can be utilised to test various impeller/injection combinations for various liquid/gas contents of the fluid being pumped,

Figure 4-7 illustrate various configurations of impeller design, wherein for example as shown in figure 4, an impeller for a standard liquid centrifugal pump would have contained seven vanes, there are now provided only three to thereby increase the passageway,

Figure 8 is a schematic view of the velocity triangles of fluid and impeller at the entrance to the impeller region.

DETAILED DESCRIPTION OF THE INVENTION

The decrease in efficiency of pumping multi-phase flow suggests that some additional loss mechanisms arise when gassy liquids are pumped. The decrease in head is greater than that which can be associated with the decrease in average density of the liquid-gas mixture. The pump performance decreases continuously as the gas volume increases until at a certain critical gas content the pump loses prime. The above trend is common to radial, mixed, and axial-flow type pumps either in single or in multistage configurations. Experimental data shows that as the gas content becomes high, the range of capacities in which the pump can operate continuously decreases.

Basically the operating range appears to be limited by two phenomena:

1) gas locking or "choking" above b.e.p. (break even point) capacity, and

2) instability in the head-capacity curve which causes surge.

The main mechanism that seems to control the surge and choking phenomena are by separation of the gas phase from the liquid phase and tendency to coalescence in a large gas pocket at the blade entry throat and sonic choking due to the reduction of speed of sound. The various pressure fields which operate inside the impeller blades play a critical role in the above two mechanisms.

The pressure fields are generated by

a) centrifugal and coriolis forces,

b) aerodynamic or blade forces, and

c) inertial forces that are associated with the acceleration/deceleration of the fluid particles in the stream direction.

The following parameters could be considered as the key influence on the pump performance in two-phase flow:

* Gas content,
* Pressure rise across the pump,
* Suction pressure,
* Rotational speed,
* Impeller size,
* Nature of thermodynamic transformation of the two-phase flow media,
* Geometry of the impeller, both the meridional shape (centrifugal, mixed, axial flow) and

the blading,

* The optimum bleeding range from delivery to suction side using the appropriate nozzle unit, and

* Operating capacity as a fraction of the bep flow.

In proving testing facilities for the present invention the suction pipe is modified to allow the introduction of air into the pipe and also injection of small amounts of water. A standard gas separator is mounted in the discharge piping to separate the air and water. This separator allows tests of the "slugging" ability of the pump by rapidly switching from air to water operation. A bleeding control system is placed on the discharge pipe with suitable nozzle unit(s) placed at an optimum position ahead of the pump impeller on the suction pipe. The pump is initially tested on water to establish a base performance level for comparison with the multi-phase performance. In this test, the pump is operated in the normal mode with water being drawn from the suction pit and discharged through a pressure control valve back to the pit. The capacity is measured at various discharge pressures to obtain the characteristic performance on water. A series of tests is then to be conducted with increasing amounts of air being drawn into the inlet pipe. The air flow rate is measured with a variable area flow meter adjusted to the pump inlet pressure. At low void fractions, the water is drawn from the pit and measured by a venturi, as in the water only test. At higher void fractions, the suction valve is closed and the water is injected into the suction pipe, with the flow rate measured by another variable area flow meter. This allows testing at many different gas void fractions. Several other tests are also recommended to determine the effect of varying speed on performance of the pump.

With the new arrangement of bleeding as broadly described in our PCT specification PCT/NZ99/00029 and that shown in the drawings of the present specification, and correct impeller design, a radical solution is offered to handle a multi-phase flow. For pumping multi-phase flow with gas/steam content variable from zero percent to 100 percent in oil/geothermal production industry a special pump can emerge, namely the rotodynamic pump using bleeding system. A pump, having the impeller blades profiles specially designed to prevent the separation of the (gas/steam) is proposed. Prior art rotodynamic pump have moved to increasing the intake area of the impeller by increasing the diameter of the impeller. Such prior art pumps have kept the same number of blades but by increasing the diameter, the intake area between each blade increases. The present invention endeavours to avoid having to increase the diameter of the impeller by removing some of the veins on the impeller to thereby increase the intake area. During pumping of multi-phase fluids gas starts to accumulate at the start of the pump and this results in a pocketing of the fluid. It is much like when certain pumps require priming to remove any air from the system prior to the pump operating efficiently. It is suggested

by the inventor that with larger passages the problems with pocketing should be alleviated. This in conjunction with upstream flow modification by injection of fluid into the intake conduit, it is suggested, will improve the efficiency and effectiveness of rotodynamic pumps, to handle multi-phase fluids. Although Furukawa as mentioned before suggests providing increased passage ways for the impeller of the centrifugal pump, this is achieved by increasing the diameter of the pumps which have been tested. Such an increase in diameter it is suggested results in an increase in power requirement to cope with the increase in torque demand.

The present invention proposes to compensate the increase power requirement by removing vanes from a standard impeller of a standard centrifugal pump (standard in respect of it normally pumping at or near optimum, a fluid which is 100 percent liquid) the removal of such vanes increasing the passage ways. Such increase in passage ways does increase the mass which is being drawn through the impeller and the increase in power it is suggested is compensated at least in part by providing an upstream co or counter rotation of fluid by the injection of fluid into the intake conduit. Such co or counter rotation, it is suggested it is not aimed at separating the phases of flow but merely to provide an increase in the energy of the intake flow in combination with improved flow directions.

The problem with existing attempts at pumping multi-phase flow also is with respect to sonic problems. Sonic boom type problems occur if the relative velocity of the flow and the vanes is such as to create (dependent on the state of the fluid) subsonic problems. It is suggested by the inventor that to ensure that the speed of sound is not exceeded by the vanes there is an induced flow provided to the intake fluid in such a manner to reduce this possibility. This is preferably achieved by the injection as suggested which may also aid in providing a modification of the state of the intake fluid (i.e. pressure) to furthermore reduce such an occurance of sonic boom.

In figure 2 there is illustrated a set up which includes a centrifugal pump 1 of a preferred impeller design which has the increased passageways as suggested. A bleeding system is also provided to bleed fluid from the delivery side conduits of the arrangement back into the intake side conduits of the arrangement.

Figure 3 illustrates how such an arrangement may be tested to provide optimum flow characteristics for particular phase ratios to the extent that the water/air mixture comprisingly multi-phase flow can be controlled to allow testing of the facilities in terms of impeller shape and design and bleeding control.

With reference to figure 8 the liquid to enter the impeller passages with a minimum disturbance depends on the impeller vane entrance angle b1, the capacity going through, and the impeller rotational velocity. All three of which determine the entrance velocity

triangle. At a capacity closer to normal, the vortex motion located before the impeller should be in the direction of impeller rotation to be able to enter the channel at an angle approaching b1. The expected reduction in relative velocity in this case has no effect on the value of the rotational velocity. On the other hand, the absolute velocity C1 is tending to increase, with a consequence of a larger tangential component for the absolute velocity Cu1, finally having a direct positive effect on pump head.

DATED THIS 21st DAY OF July 1999
A.J. PARK & SON
PER S. Nightingale.
AGENTS FOR THE APPLICANT

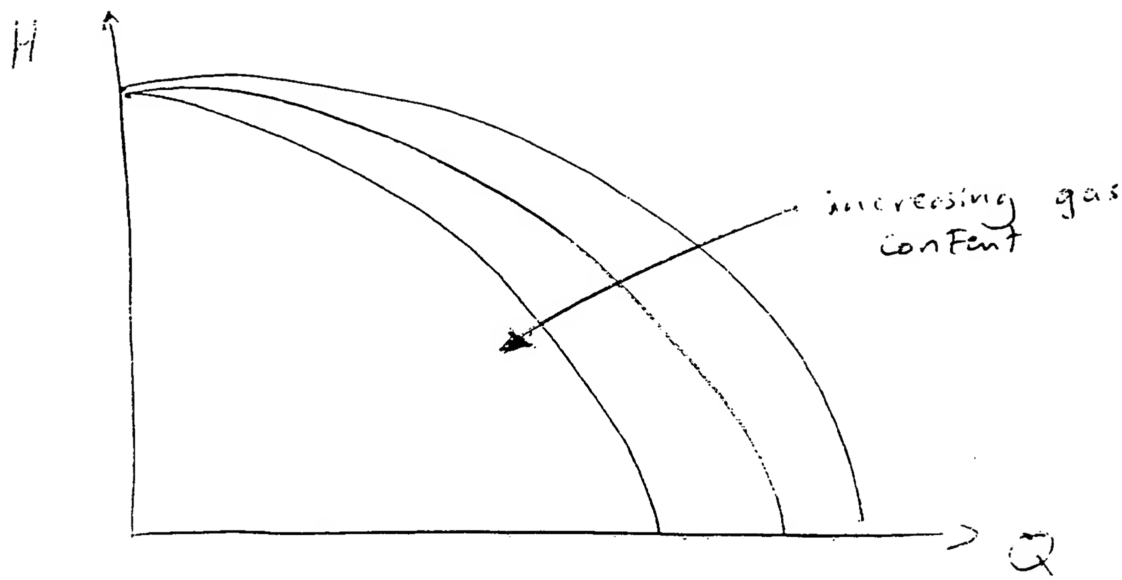
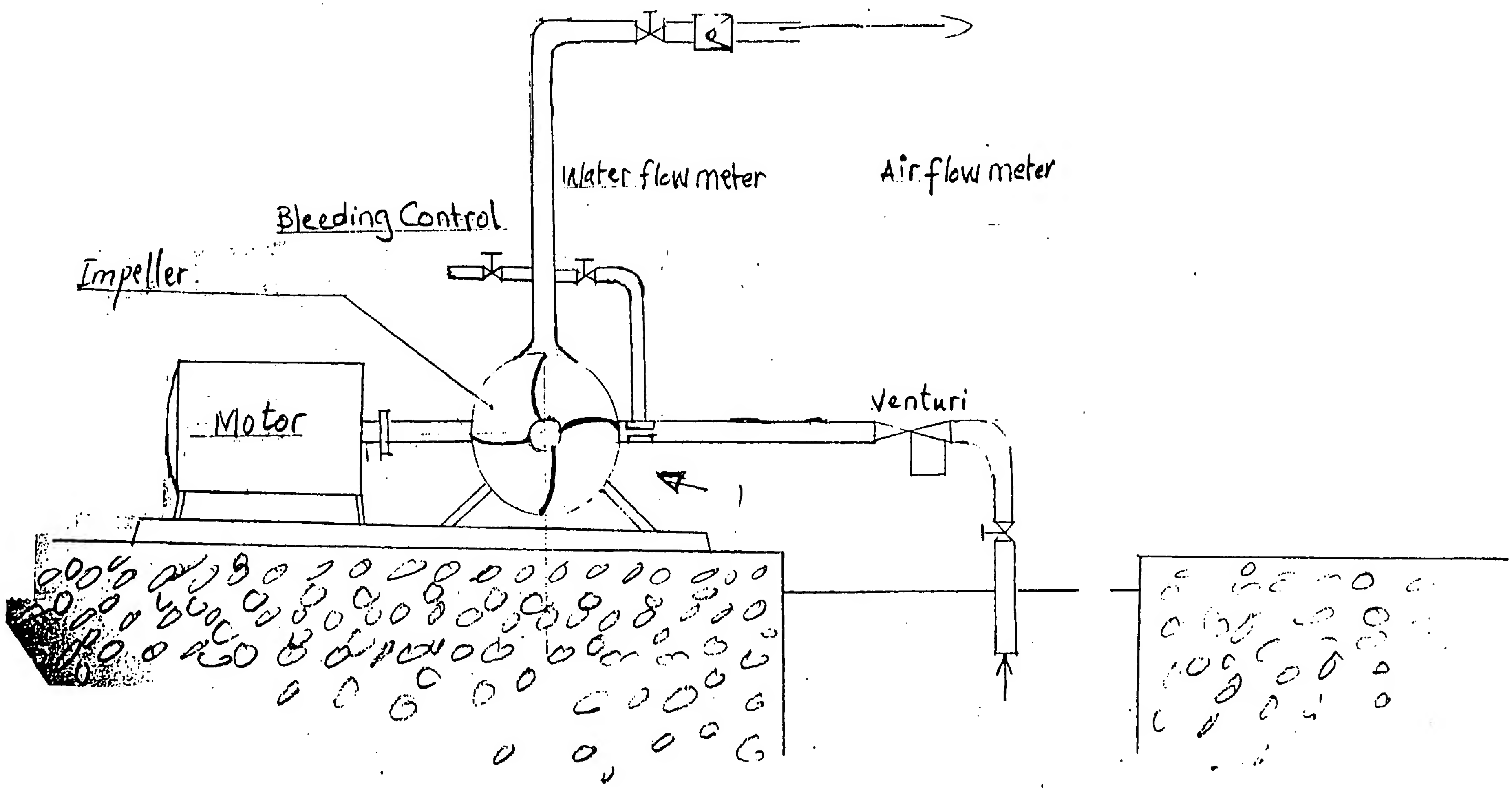


Figure 1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Air flow meter
Bleeding Control
Impeller
Motor
Venturi

Figure 2

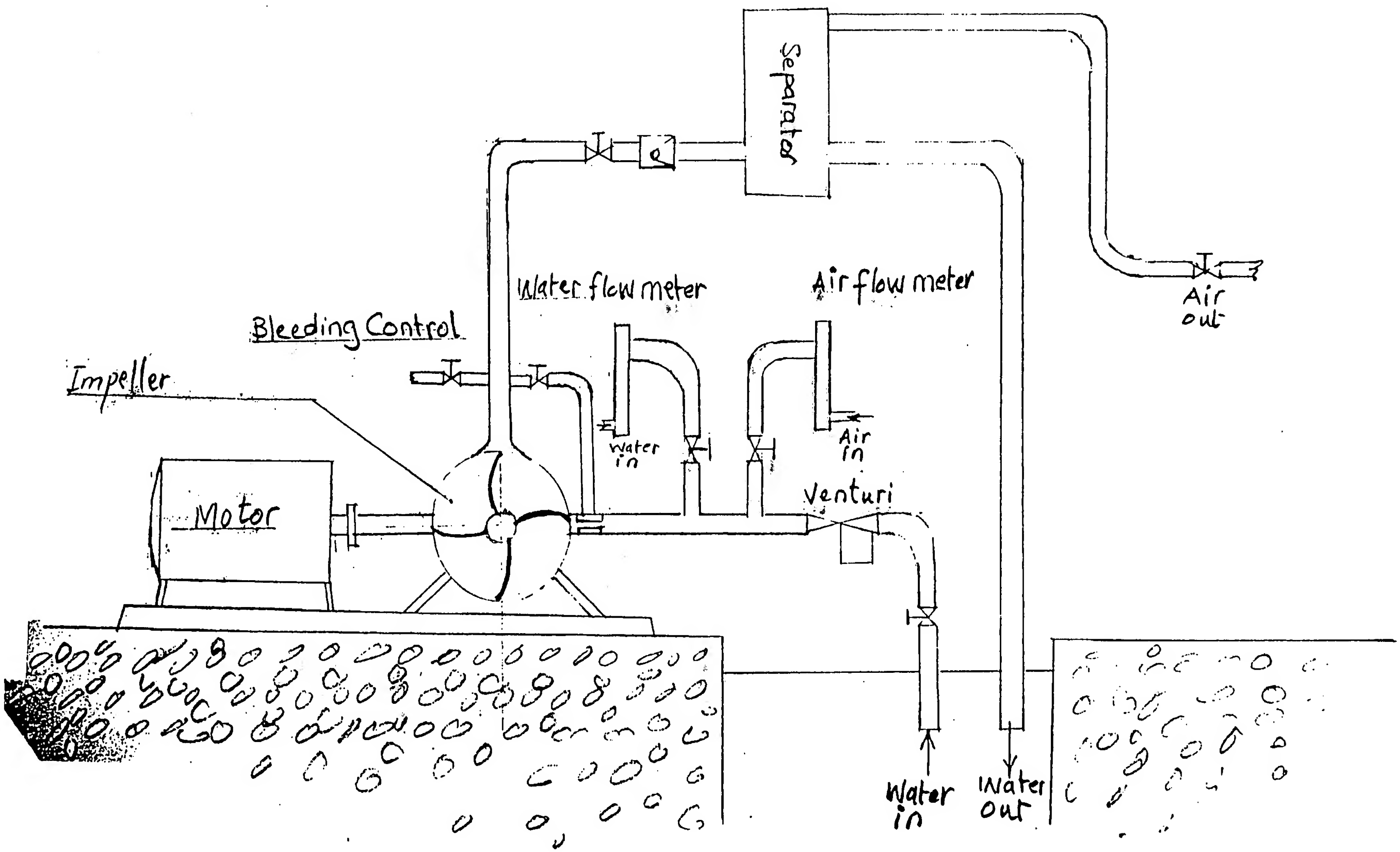

Separator
Air out
Water flow meter
Air flow meter
Bleeding Control
Impeller
Water in
Air in
Venturi
Motor
Water in
Water out

Figure 3

In A_1

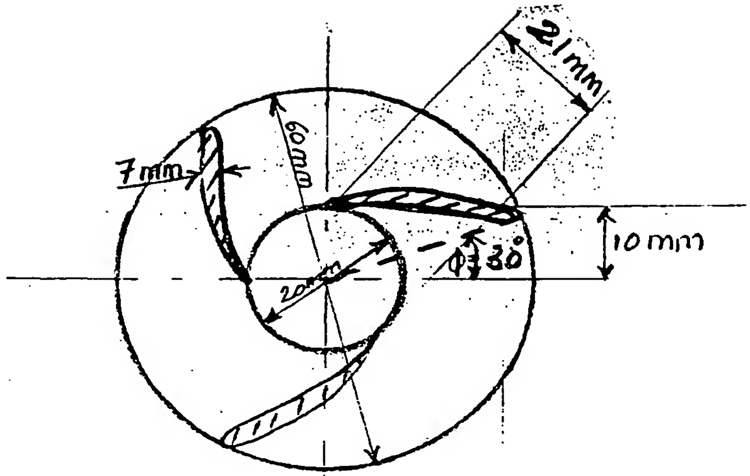
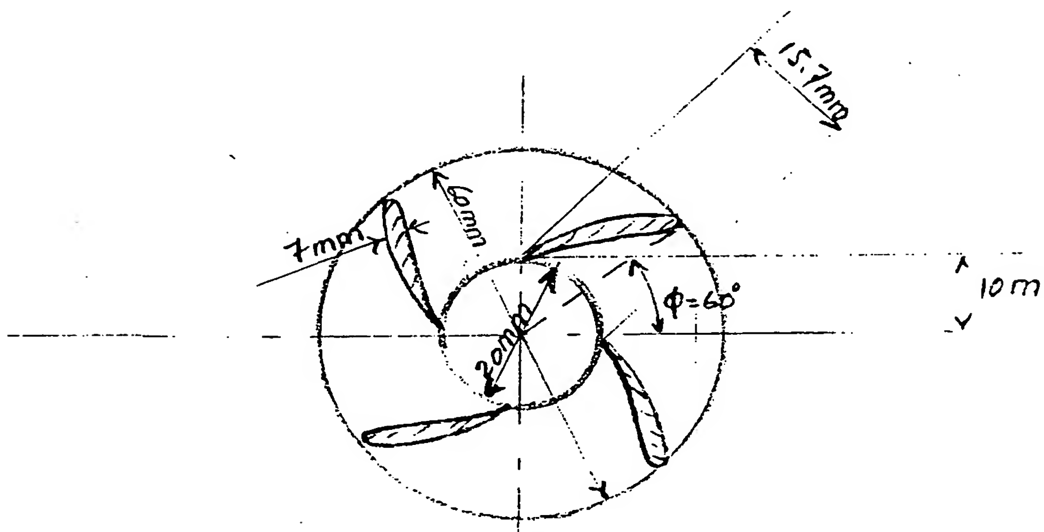


Figure 4

inlet angle $\theta_i = 26°$

outlet angle $\theta_o = 23°$



inlet angle $\theta_i = 26°$

Figure 5

outlet angle $\theta_o = 23°$

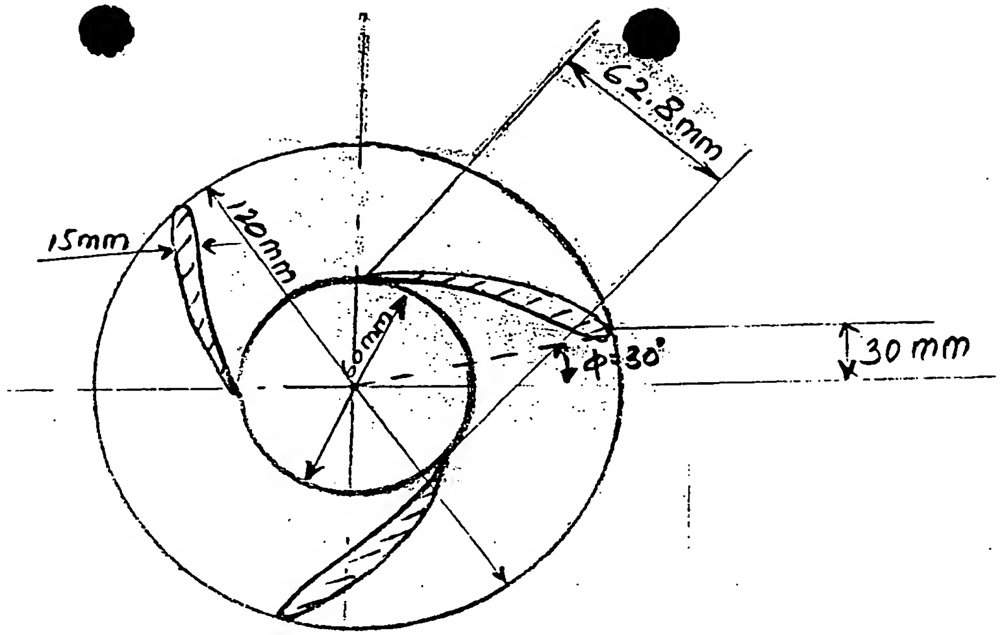


Figure 6

Inlet angle $\theta_i = 26°$

Outlet angle $\theta_o = 23°$

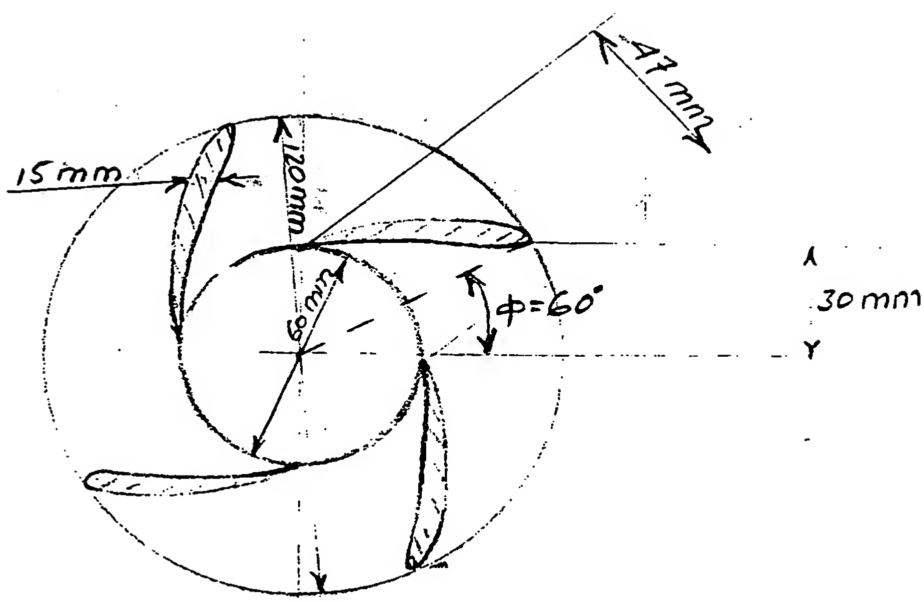
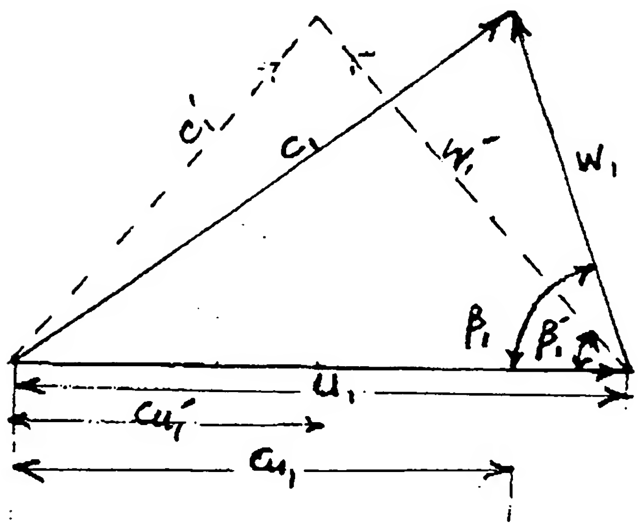


Figure 7

Inlet angle $\theta_i = 26°$

Outlet angle $\theta_o = 23°$



Velocity triangle at entrance.

Figure 8